SHAPE AND CONFIGURATION DESIGN SENSITIVITY ANALYSIS AND DESIGN OPTIMIZATION OF HIGH FREQUENCY STRUCTURAL-ACOUSTIC PROBLEMS USING ENERGY FINITE ELEMENT METHOD

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Energy Finite Element Method (EFEM) has been developed based on the energy conservation in coupled structures following a wave approach and taking advantage of traditional finite element approximation. In solving for the space- and time- averaged energy density in coupled structural systems in high frequency range, EFEM can accurately predict the structural-acoustic response and identify the energy flow path, which, by comparison over traditional FEM and BEM, makes it a much more efficient design tool for high frequency structural-acoustic problems.

For the purpose of optimizing structures for best acoustic comfort with least usage of materials using a gradient-based optimization algorithm, a design sensitivity analysis (DSA) method for EFEM is developed in this paper. Built-up structural systems comprised of structural panels coupled with acoustic medium are studied. Configuration design of the structural panels and shape design of panel areas are considered for sensitivity analysis. Design optimization is carried out to reduce noise and vibration level while minimizing the structural weight.

In this paper, EFEM is used to predict the high frequency structural-acoustic response. In order to model coupled structural-structural and structural-acoustic behaviors, the analytical method proposed by Langley and Heron is used to calculate the power transfer coefficients between structural panels and the Leppington's numerical model is used to evaluate the radiation efficiency of a plate, which quantifies the interaction between structural panels and the acoustic medium.

Based on the governing equation of EFEM, the continuum design sensitivity formulation is derived, while the discrete method is applied in the variation of the structural-structural and structural-acoustic coupling matrix. Both the direct differentiation and adjoint variable method are developed for sensitivity analysis, where the difficulty of the adjoint variable method is overcome by solving a transposed system equation. The proposed design sensitivity formulation is numerically implemented for shape and configuration design variables, and the numerical sensitivity results show excellent agreement comparing with the finite difference results.

A simplified passenger vehicle model is constructed and studied. A design optimization problem is formulated where the shape and configuration parameters are defined as design variables. The design optimization is carried out such that the noise and vibration level in the passenger compartment is reduced while minimizing the weight.

Key Words:
Energy Finite Element Method (EFEM), Structural Acoustics, Shape and Configuration Design Sensitivity Analysis (DSA), Adjoint Variable Methods, Design Velocity, Design Optimization